MAX phase thin films: From design and processing to environmental resistance

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MAX phases constitute a family of inherently nanolaminated ternary ceramics (carbides and nitrides), which are promising for a variety of applications because of their unique combination of ceramic and metallic properties. MAX phases are described by the general formula Mn+1AXn, where M is a transition metal, A is an A-group element and X is either carbon or nitrogen, and n = 1, 2, 3. To this day, there are close to 150 known MAX phases which are developed either for high temperature and tribological applications, to name a few, or for the synthesis of their 2D derivatives (MXenes). The chemical versatility of MAX phases was also showcased by the possibility of forming solid solutions on the M, A and X sites. Employing solid solutions has allowed to improve the phase purity and confer different properties to the formed MAX phases.

In the last 10 years or so, the oxidation resistance of selected MAX phases has been a core topic as their self-healing and self-protective behavior was demonstrated. Indeed, because of their hexagonal structure and atomic arrangement, MAX phases are able to release the weakly-bonded A elements (often Al) which react with the oxidizing atmosphere and form a protective oxide scale. In the case of Cr2AlC oxidation at temperatures above 1000 °C, the loss of Al often leads to the local decomposition of the MAX phase into Cr7C3 immediately below the newly formed Al2O3 scale. This decomposition is usually accompanied by pore formation which is detrimental to the mechanical and thermal stability of the MAX phase. However, not all Al-containing MAX phases behave in the same manner. V2AlC tends to form a complex oxide scale which is primarily composed of V-oxides. The protective nature of the oxide scale, relies significantly on the microstructure and density of the initial MAX phase film and the growth of the oxide grains.

This presentation will be axed around two main topics: the application-oriented design and thin film processing of solid solution MAX phases, and the oxidation resistance of selected Al-based MAX phases. The design considerations made in the selection of the material system, as well as the processing conditions including target choice (elemental, composite, compound), sputtering mode and deposition conditions will be described. Finally, the oxidation of selected MAX phases will be discussed and strategies for improving the oxidation resistance of Cr2AlC will be presented.